

EVALUATING METHODS TO INCREASE THE COMPRESSIVE STRENGTH OF RECYCLED LINERBOARD

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ABSTRACT

The compressive strength of handsheets produced by re-slushing dried linerboard is significantly less than that of handsheets made from original never-dried pulp. This is also true for tensile and burst strengths. Tensile and burst strengths of re-slushed linerboard can be significantly improved by chemical and mechanical treatments. The objective of this study was to determine whether compressive strength could be improved by chemical treatment. Several potential treatments were performed on repulped material. No treatment was effective in increasing compressive strength. The simplest and least expensive way of initially increasing compressive strength at high freeness levels is by beating the pulp. For additional compressive strength, a sodium hydroxide treatment was selected for use with alkaline beating. Although this combination significantly increased tensile and burst strengths, it had no effect on compressive strength. The effect of increased wet pressing followed by restraint drying (IPD) on the best combination of alkaline treatment and alkaline beating was evaluated. The sequence of alkaline treatment, followed by alkaline beating, followed by IPD treatment produced an increase in compressive strength. The improvement in strength was about 11% greater than that for handsheets made from never-dried pulp. Further study is needed to determine whether or not alkaline beating is required.

INTRODUCTION

Dried linerboard that is repulped (re-slurried in water) and reformed into linerboard has a significantly lower compressive strength than does linerboard produced from the original, never-dried pulp (1). Drying causes changes in the fibers that result in reduced tensile and burst strengths (2); those changes

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also reduce compressive strength (3). This reduced strength of repulped dried linerboard pulp can be increased by beating the pulp; however, this simultaneously reduces the pulp freeness.

It is well known that chemical treatments can increase the tensile and burst strengths of dried pulps. We thought that a chemical treatment might increase the compressive strength without greatly reducing the freeness. Thus, the purpose of this study was to evaluate several potential chemical treatments for their effectiveness in increasing the compressive strength of repulped, dried linerboard pulp.

Initially, several chemical treatments were applied to the repulped dried linerboard, and their effects on compressive strength were determined. The sodium hydroxide treatment was then selected for evaluation in combination with mechanical treatment or beating under alkaline conditions. Finally, the effect of increased wet pressing followed by restraint drying (IPD) treatment on the best combination of sodium hydroxide treatment and alkaline beating was determined.

RESULTS AND DISCUSSION

Effect of Chemical Treatment

The chemical treatments used and the reaction conditions employed are given in Materials and Experimental Procedures. The STFI² compressive strength results for the 2% sodium hydroxide (on pulp) treatments are given as a function of Canadian Standard Freeness (CSF) in Figure 1. The strength results are given as STFI compressive strength divided by basis weight so as to eliminate the effect of the varying basis weights of the handsheets used. For purposes of comparison, the never-dried pulp and the dried repulped linerboard data are also included in Figure 1. The results for the five repulped linerboard pulps treated with 2% sodium hydroxide varied greatly. Therefore, only the data for the pulps giving the highest and the lowest compressive strengths are shown. From these data, it appears that, on average, 2% sodium hydroxide treatment had little effect on compressive strength. The reason for the large variability of the data is not known; reducing variability may involve increasing the number of tests for each data point.

Density is thought to be more of a basic property of the handsheet than is pulp freeness. As Figure 2 shows, compressive strength is obviously a function of sheet density; however, other factors also seem to be involved as well. The repulped linerboard was also treated with 4%, 6%, and 8% sodium hydroxide (on pulp). Data for these treatments are between the 2% NaOH best and worst treatments shown in Figures 1 and 2. Increasing the sodium hydroxide concentration appeared to have no effect on compressive strength, although increasing the concentration is known to increase tensile and burst strengths (1).

The effects of alkaline hydrogen peroxide treatments on compressive strength are shown in Figure 3. Again, because of the large variability, only the data for the best and the worst treat-

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ments are shown. Although the alkaline peroxide treatments somewhat increased the final sheet densities, these treatments did not significantly increase compressive strength.

The data for the best and worst peroxymonosulfuric acid treatments are given in Figure 4. Again, the treatments did not significantly increase compressive strength. However, the best treatment did greatly increase the unbeaten sheet density and the compressive strength for the unbeaten pulp to values greater than that for the never-dried unbeaten pulp (compare left ends of lines). The best treatment decreased the freeness of the unbeaten pulp from 650 to 610 ml.

The alkaline peroxymonosulfate treatment showed no positive effect and is not shown. The best oxygen delignification treatments showed a slight positive effect, and the best point is shown in Figures 1 to 4.

Although the compressive strength data from the chemical treatments were highly variable, it appears that chemical treatments, even those that delignify the pulp, do not increase compressive strength. For unbeaten pulp, a delignifying treatment, such as peroxymonosulfuric acid followed by alkaline extraction, may increase the original unbeaten compressive strength. However, this increase can be simply achieved by slightly beating the untreated pulp. Fellers showed that, when comparing sheets at a given density, the extent of delignification by the kraft process had a negligible influence on compressive strength (3). The compressive strength data for the various chemical treatments, compared at a sheet density of 750 kg/m^3 , are given as a function of lignin content in Figure 5. Although the data scattered widely, there was no apparent increase of compressive strength with decreasing lignin content as would be found with properties such as tensile, burst, and tear strength. Thus, as Fellers found in the kraft system, delignification of the pulp, regardless of the system employed, does not appear to significantly influence compressive strength.

A previous study showed that alkaline treatments will significantly increase the tensile, burst, and tear strengths of high-yield pulps (4). On review of the chemical treatment data, one 2% sodium hydroxide treatment followed by beating gave the second highest compressive value thus far in the study reported here. Only the best oxygen treatment gave a slightly higher value (see Figs. 1-4). If we rule out the oxygen treatments because they require a pressure vessel, then the 2% sodium hydroxide treatment gave the highest compressive strength value. Although, as previously noted, the sodium hydroxide treatments, on average, showed no positive effects on compressive strength, we decided to investigate if such a treatment followed by beating of the pulp under alkaline conditions might increase compressive strength. Several studies have shown that beating under alkaline conditions increases tensile and burst strengths (1,5,6). The alkaline beating was carried out by simply not washing the pulp between the alkaline treatment and the beating stage.

Effect of Alkaline Beating

We studied the effect of a 2% sodium hydroxide treatment on the dried repulped linerboard pulp followed immediately by beating in the PFI mill without an intermediate washing step (which was done in previous work). The pulp was thoroughly washed after beating. Sufficient 205-g/m^2 handsheets were prepared so that tensile, tear, and burst strengths could be

determined in addition to the STFI compressive strength. We felt that mixing chemicals with the pulp might have been inadequate in the previous work, so a Hobart mixer was used to thoroughly mix the sodium hydroxide solution with the pulp. For purposes of comparison, one treatment was hand mixed as was done previously. A treatment temperature of 80°C had been used for all previous sodium hydroxide treatments. In this part of the work, room temperature (about 23°C) was used and contrasted with one treatment at 80°C . Mixing during this treatment was done in a small rotary digester because the Hobart mixer could not be used at 80°C . It is well known that wood fibers treated with alkali swell to a greater extent at lower temperatures. The untreated control pulp, the hand-mixed pulp, and one Hobart-mixed pulp treated at room temperature (23°C) were washed to remove the alkaline prior to PFI beating.

The results of these experiments are summarized in Table I. Burst strength of the untreated and treated pulps is given as a function of density in Figure 6. The sodium hydroxide treatment that was hand mixed significantly increased burst strength. Hobart mixing increased burst strength somewhat, as did alkaline beating. Treatment at 80°C , with mixing in the rotary digester followed by alkaline beating, was less effective than was the Hobart mixing sequence at room temperature. Alkaline treatment with Hobart mixing followed by alkaline beating, all at room temperature, gave the largest increase in burst strength. Tensile strength trends were essentially the same as were the burst strength trends.

Figure 7 shows tear strength as a function of burst strength. Hobart mixing seemed to have nearly as much effect on tear strength as did alkaline beating. It seemed that putting energy into the fiber when it is alkaline swollen at room temperature increased tensile, tear, and burst strengths. Hobart mixing is less energy intensive than is PFI beating and seems to have somewhat less effect. Energy inputs were not measured, and it is not possible to quantitatively compare these effects. In any event, mechanically treating alkaline swollen fibers seemed to increase tensile, tear, and burst strengths.

The compressive strength for the Hobart mixed, 2% sodium hydroxide treated, alkaline beaten, dried, repulped linerboard fiber is given as a function of sheet density in Figure 8. This best of treatments for increasing the usual strength properties had no effect on increasing compressive strength and actually decreased it. Thus, although alkaline beating, or more generically mechanical treatment of alkaline swollen fibers, effectively increases tensile, tear, and burst strengths, it has a negative effect on compressive strength.

Because all previously studied methods, except for beating, failed to increase compressive strength and because increased pressure in wet pressing is known to increase sheet density, we decided to study the effect of increased wet pressing, followed by restraint drying (IPD), on compressive strength.

Effect of IPD

The effects of IPD on untreated dried, repulped linerboard fiber were studied. However, since alkaline treatment and alkaline beating increased tensile, tear, and burst strengths, the effects of IPD on alkaline-treated and alkaline-beaten, dried, repulped linerboard fiber were also studied. The alkaline treatment was 4% sodium hydroxide on pulp, and the alkaline beat-

ing was conducted as previously described. Tensile, tear, burst, and STFI compressive tests were performed on handsheets produced using the following treatments:

Untreated, normal drying
Untreated, IPD treatment
4% NaOH treated, alkaline beaten, normal drying
4% NaOH treated, alkaline beaten, IPD treatment

Results of these treatments are given in Table II. The effects of alkaline treatment and IPD on burst strength are shown in Figure 9, where burst index is given as a function of freeness. Alkaline treatment followed by alkaline beating and IPD increased burst strength; the combination gave the highest values at a given freeness. Alone, IPD had only a small effect on burst. Burst strength as a function of sheet density is shown in Figure 10. Although the data are somewhat scattered, it seemed that, at a given density, IPD decreased burst strength, whereas the alkaline treatment increased it.

Figure 11 shows tensile strength as a function of density. Here, the trends seemed to be clearer than they did for burst. The IPD alone had a greater effect on tensile strength than on burst strength. At a given density, alkaline treatment followed by beating and IPD increased tensile strength. The difference in the effect of IPD on tensile and burst is undoubtedly due to its effect on elongation of the sheets at failure. Figure 12 shows elongation at failure when using the Instron tensile test. The IPD significantly decreased stretch for both treated and untreated sheets with the effect being greater for the untreated sheets.

The effect of IPD on tear strength is shown in Figure 13 where tear is shown as a function of burst. The IPD greatly decreased tearing strength. Alkaline treating followed by alkaline beating seemed to significantly increase tearing strength for both IPD and normally dried pulps.

The effect of IPD on compressive strength is given in Figure 14. For the untreated pulp, IPD increased compressive strength only after the pulp was beaten to around 500 CSF. For the alkaline-treated, alkaline-beaten pulp, IPD increased compressive strength even for the unbeaten pulp, and the effect was significantly enhanced by beating. The highest compressive strength value obtained was for the alkaline-treated, alkaline-beaten, IPD pulp beaten to a freeness of 450 ml. However, this strength was only 10% greater than that for the completely untreated dried, repulped linerboard beaten to 300 ml. Alkaline treatment followed by alkaline beating and IPD did increase compressive strength; however, simply beating the pulp gave the largest increase in compressive strength. In the work to date, the effect of alkaline treatment followed by nonalkaline beating and IPD has not been examined; therefore, the effect of alkaline beating on compressive strength of IPD dried sheets was not determined.

CONCLUSIONS

Chemical treatments alone do not significantly increase compressive strength. The only treatment sequence that increased compressive strength was alkaline treatment, followed by alkaline beating, followed by IPD. The 10% increase in compressive strength produced by this treatment sequence could probably be exceeded if the pulp was beaten to a lower freeness. In any

event, the effect of the combined alkaline treatment and IPD on compressive strength was quite modest. Beating the pulp is the simplest and probably the most inexpensive way of increasing compressive strength. To increase compressive strength at the higher freeness levels, alkaline treatment and IPD might be used. Alkaline beating may or may not be required; this area needs further study.

MATERIALS AND EXPERIMENTAL PROCEDURES

Pulps

Samples of never-dried linerboard pulp (obtained from the couch trim) and a linerboard butt roll from the same pulp were shipped to the Forest Products Laboratory from a Weyerhaeuser mill at Springfield, Oregon. The pulp was produced from a mixture of softwoods containing approximately 63% Douglas Fir, 26% Pine, 9% White Fir, and 2% other softwood.

The yield of kraft pulp was approximately 51%; the Kappa number was 90. The linerboard machine primary headbox freeness was 581 ml (CSF), and the secondary headbox freeness was 296 ml. The pH was 5.0 for the primary headbox and 4.8 for the secondary; consistency was 0.40 for the primary and 0.47 for the secondary. Alum usage was 16.3 kg/t, and rosin size usage was 1.2 kg/t.

About half the butt roll was repulped using a Morden pulper and water to a dry pulp ratio of 20:1. The pulp was then drained in a screen box, pressed to about 25% solids, shredded, and stored in a 2°C cold room until used.

Chemical Treatments

The pulp in this study was subjected to the following chemical treatments:

Sodium hydroxide:

2.0% (on pulp), 80°C, 120 min, 5% consistency (5 replications)

4.0% (on pulp), 80°C, 120 min, 5% consistency (one run)

6.0% (on pulp), 80°C, 120 min, 5% consistency (one run)

8.0% (on pulp), 80°C, 120 min, 5% consistency (one run)

Hydrogen peroxide plus sodium hydroxide:

3.0% H₂O₂ + 2.0% NaOH + 4.0% sodium silicate + 0.1% MgSO₄ (on pulp), 80°C, 120 min, 5% consistency (one run)

3.0% H₂O₂ + 4.0% NaOH (on pulp), 80°C, 120 min, 5% consistency (one run)

3.0% H₂O₂ + 6.0% NaOH (on pulp), 80°C, 120 min, 5% consistency (one run)

3.0% H₂O₂ + 8.0% NaOH (on pulp), 80°C, 120 min, 5% consistency (one run) (worst on Fig. 3)

3.0% H₂O₂ + 8.0% NaOH + 4.0% sodium silicate + 0.1% MgSO₄ (on pulp), 80°C, 120 min, 10% consistency (two runs) (best on Fig. 3)

6.0% H₂O₂ + 8.0% NaOH + 4.0% sodium silicate + 0.1% MgSO₄ (on pulp), 80°C, 120 min, 10% consistency (one run)

Peroxymonosulfuric acid followed by sodium hydroxide extraction (washing between stages):

10% H₂SO₅ (on pulp), 22°C, 24 h, 5% consistency, followed by 1.0% NaOH, 50°C, 60 min, 10% consistency (three replications)

10% H₂SO₅ (on pulp), 22°C, 24 h, 5% consistency, followed by 1.0% NaOH, 50°C, 60 min, 10% consistency (one run)

10% H₂SO₅ (on pulp), 50°C, 120 min, 10% consistency, followed by 1.0% NaOH, 50°C, 60 min, 10% consistency (one run) (worst on Fig. 4)

20% H₂SO₅ (on pulp), 22°C, 24 h, 10% consistency, followed by 1.0% NaOH, 50°C, 60 min, 10% consistency (one run) (best on Fig. 4)

31% H₂SO₅ (on pulp), 22°C, 24 h, 10% consistency, followed by 1.0% NaOH, 50°C, 60 min, 10% consistency (one run)

31% H₂SO₅ (on pulp), 40°C, 8 h, 10% consistency, followed by 1.0% NaOH, 50°C, 60 min, 10% consistency (one run)

Peroxymonosulfate plus sodium hydroxide:

Oxone was used to supply the peroxymonosulfate employed in this treatment.

32% Oxone + 8.0% NaOH (on pulp), 50°C, 60 min, 10% consistency (one run)

Oxygen plus sodium hydroxide:

4.0% NaOH (on pulp), O₂ pressure 1,030 kPa, 120°C, 60 min, 5% consistency (one run)

4.0% NaOH (on pulp), O₂ pressure 1,030 kPa, 120°C, 90 min, 5% consistency (one run)

8.0% NaOH (on pulp), O₂ pressure 1,030 kPa, 140°C, 5 min, 5% consistency (one run) (best on Figs. 1, 2, 3, 4, and 14)

Chemicals

The sodium hydroxide and 30% hydrogen peroxide were reagent grade. Peroxymonosulfuric acid was produced by mixing (dropwise) 70% hydrogen peroxide (supplied by E.I. de Nemours du Pont, Inc., Wilmington, Delaware, as Albone 70) into cold (2°C) concentrated sulfuric acid. Oxone was purchased from the Aldrich Chemical Co., Milwaukee, Wisconsin.

Procedures

Pulps were washed after treatment and then beaten to several freeness levels in a PFI mill. Washing after the chemical treatment was important to make reproducible results, because the white water from the handsheet making was not recirculated. Handsheets, 205 g/m², were prepared using TAPPI methods. Wet pressing was performed by automated controls to eliminate the effect of pressing variables on strength properties. Heavy handsheet weight was selected to reduce fines loss in sheet making. The sheets were tested for the usual strength properties using TAPPI methods and for compressive strength using the SCAN standard method for the STFI compressive tester.

Alkaline Beating

The pulps were beaten in a PFI mill under alkaline conditions. The pulp went directly from alkaline treatment to the PFI mill; no intermediate washing was involved.

IPD Treatment

Some handsheets were given a moderate IPD treatment. The handsheets were pressed under 345 kPa for 1 min between blotting paper. Handsheets were then pressed between four blotters for 10 s at 4,137 kPa. This high pressure was used to effect the tendency of once-dried fibers to spring back after light pressing. At this point, the handsheets were about 45% solids. The sheets were then dried under restraint between circular screens. That is, the screens were cut to contact the handsheets on only the outer circumference. The hold-down pressure was 1,034 kPa. The platens were heated to 149°C, and the heating time to reach complete dryness was 9 min.

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Table 1. The effect of alkaline beating on dried, repulped kraft linerboard

Treatment	Freeness (CSF)	Fiber length (mm)	Fines (%)	Density (kg/m ³)	Tensile strength (Nm/g)	Average Emax ^a (%)	MOE (GPa)	Tear strength (MPa)	Burst strength (kPa·m ² /g)	Tear strength (mN·m ² /g)	PFI ^b (revolutions)	STFI compressive strength/basis weight
Dried repulped, control	630	2.07	4.28	585	42.4	3.27	2.74	0.638	3.28	19.9	0	— ^c
	590	2.30	3.22	669	58.7	3.71	2.81	1.060	4.95	20.0	1,800	—
	490	2.13	3.72	678	59.4	3.37	3.16	1.010	4.97	20.2	3,300	—
	400	2.22	2.87	718	67.1	3.36	3.14	1.192	5.81	19.2	5,500	—
	340	2.12	2.80	753	67.9	3.95	3.66	1.446	5.76	18.9	7,500	—
2% NaOH hand-mixed at 23°C	640	2.28	2.59	607	49.4	2.97	2.97	0.675	4.41	20.3	0	0.0226
	550	2.31	2.75	634	57.2	3.73	2.87	0.984	4.83	20.2	1,500	0.0254
	510	2.23	2.97	660	64.6	3.48	3.46	1.060	5.34	19.9	3,300	0.0265
	450	2.30	2.30	690	66.4	4.14	3.06	1.345	5.58	19.7	6,000	0.0277
	400	2.23	3.13	704	69.6	4.29	3.53	1.510	6.01	19.2	8,100	0.0290
2% NaOH Hobart-mixed at 23°C	630	2.23	3.02	605	53.2	3.68	2.45	0.889	4.91	21.4	0	0.0236
	560	2.30	2.72	638	62.3	3.91	3.43	1.153	5.36	21.3	1,500	0.0255
	530	1.94	4.20	660	64.6	3.80	2.96	1.179	5.44	20.9	3,300	0.0258
	460	2.21	2.62	676	67.1	4.00	4.23	1.371	5.67	21.0	6,000	0.0277
	410	2.31	3.03	708	67.4	4.16	3.50	1.415	5.84	20.7	8,100	0.0292
2% NaOH Hobart-mixed and alkaline-beaten at 23°C	630	2.29	2.96	632	57.0	3.82	3.05	1.008	5.25	21.6	0	0.0243
	530	2.41	2.36	660	68.4	4.11	3.18	1.312	5.87	21.0	1,500	0.0264
	490	2.29	2.62	667	66.4	3.76	3.36	1.193	5.92	20.8	3,300	0.0267
	420	2.31	2.72	684	68.0	3.74	3.18	1.230	6.29	20.3	6,000	0.0294
	380	2.35	2.54	698	72.7	4.12	3.69	1.500	6.16	20.1	8,100	0.0281
2% NaOH tumbling digester, mixed and alkaline-beaten at 80°C	700	2.32	2.57	578	47.0	3.70	2.21	0.769	4.29	21.9	0	0.0220
	520	2.31	2.65	656	61.1	3.62	2.74	1.038	5.33	21.0	1,800	0.0253
	480	2.32	2.62	690	63.0	3.32	3.40	1.023	5.93	20.2	4,500	0.0279
	420	2.31	2.31	709	66.9	3.62	3.25	1.213	6.19	19.9	6,600	0.0292
	380	2.41	2.04	718	66.6	3.79	3.40	1.285	6.21	19.8	9,000	0.0287

^aElongation at rupture.

^bPFI mill.

^c— is no data.

Table II. The effect of increased pressing and restraint drying (IPD) on dried, repulped kraft linerboard

Treatment	Freeness (CSF)	Density (kg/m ³)	Time-in-PFI (revolutions)	Burst index (kPa·m ² /g)	Tear strength (mN·m ² /g)	Tensile index (Nm/g)	E _{max} ^a (%)	STFI compressive strength/basic weight
Untreated, normal dried	670	562	0	3.23	20.7	36.06	2.80	0.0204
	590	632	1,500	4.83	20.5	55.47	2.76	0.0269
	540	673	3,300	5.31	20.9	60.69	3.35	0.0268
	460	686	6,000	5.75	21.3	64.08	3.69	0.0287
Untreated-IPD	670	598	0	3.48	19.8	47.44	1.77	0.0228
	590	702	1,500	5.04	18.3	71.80	2.71	0.0292
	540	710	3,300	5.47	18.2	75.58	2.80	0.0321
	460	724	6,000	5.75	17.6	74.39	2.83	0.0342
4% NaOH, alkaline-beaten, normal dried	680	594	0	4.42	21.8	50.92	3.10	0.0236
	590	630	1,500	5.30	21.5	66.14	3.12	0.0269
	520	680	6,000	5.52	20.9	65.79	3.55	0.0284
	450	707	10,500	5.91	20.7	70.05	3.37	0.0297
4% NaOH, alkaline-beaten, IPD	680	660	0	4.97	19.2	61.09	3.01	0.0286
	590	690	1,500	5.72	17.9	76.31	2.62	0.0311
	520	713	6,000	5.87	18.0	81.95	3.16	0.0357
	450	738	10,500	6.20	18.2	80.87	3.28	0.0361

^aElongation at rupture.

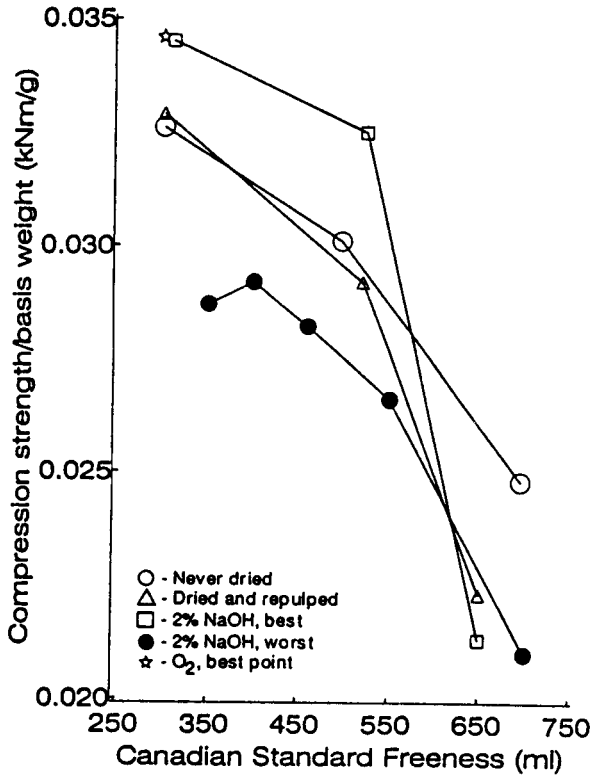


Figure 1. STFI compressive strength divided by basis weight for 2% NaOH treatments as function of freeness.

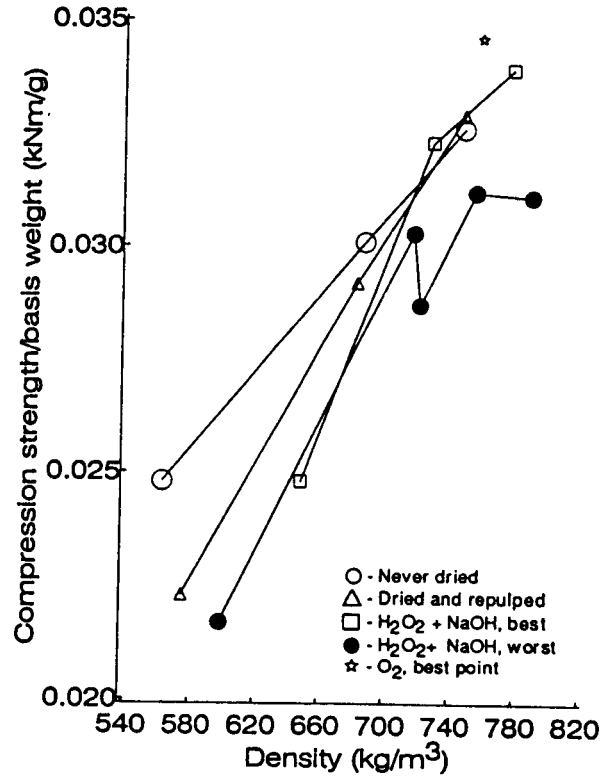


Figure 3. STFI compressive strength divided by basis weight for alkaline hydrogen peroxide treatments as function of hand-sheet density.

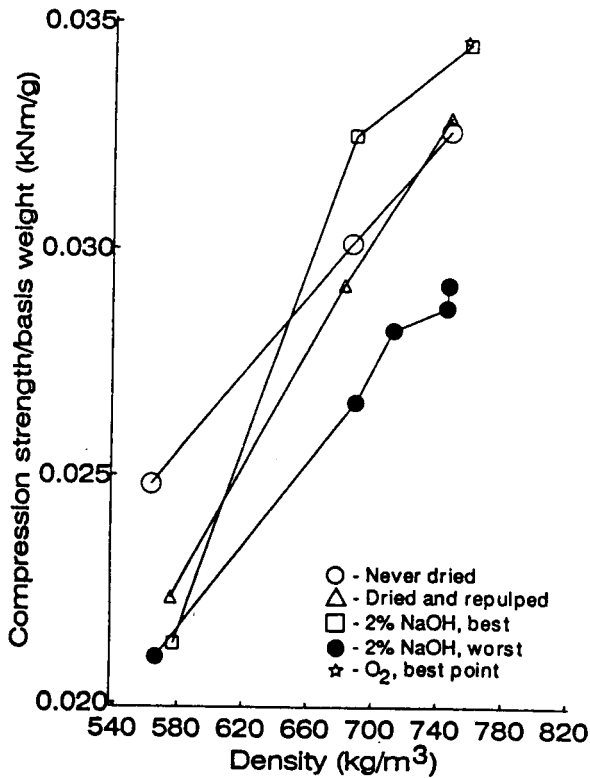


Figure 2. STFI compressive strength divided by basis weight for 2% NaOH treatments as function of handsheet density.

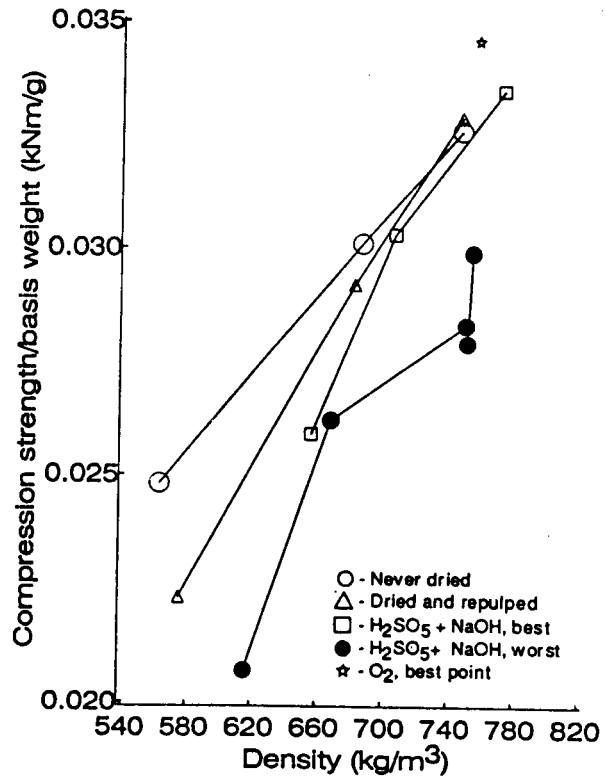


Figure 4. STFI compressive strength divided by basis weight for peroxymonosulfuric acid treatments as function of hand-sheet density.

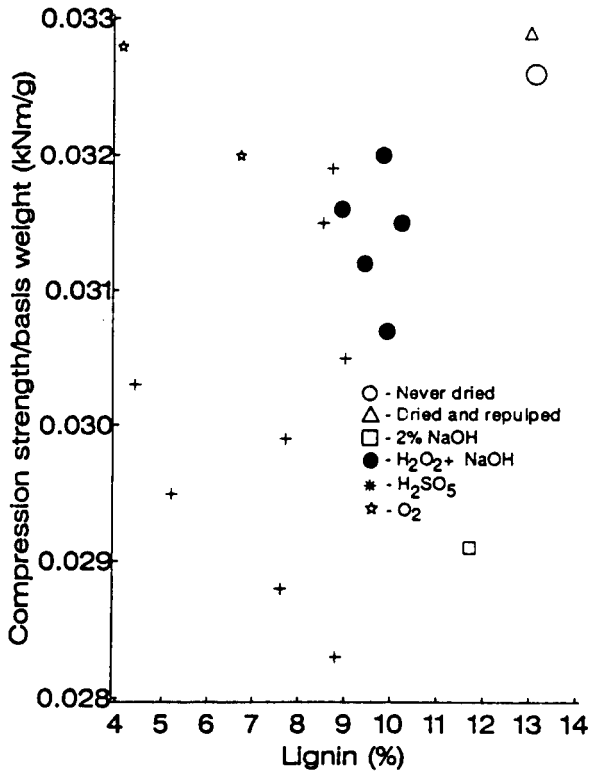


Figure 5. STFI compressive strength divided by basis weight at handsheet density of 750 kg/m³ as function of lignin content of the pulp for various chemical treatments.

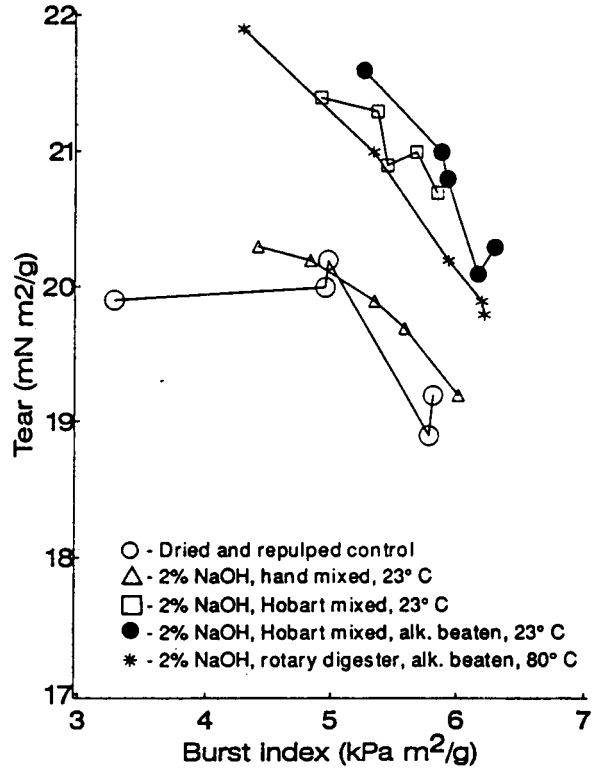


Figure 7. Tear strength of untreated and treated pulps as function of burst strength.

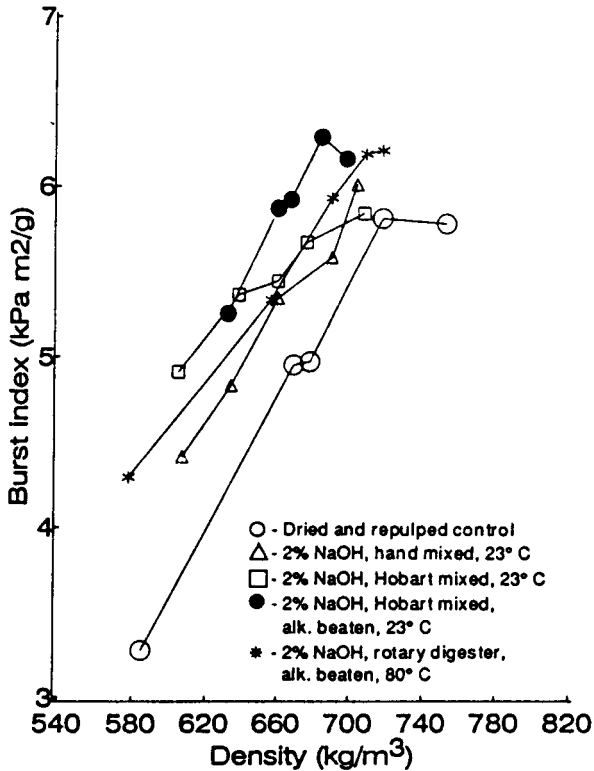


Figure 6. Burst strength of untreated and treated pulps as function of handsheet density.

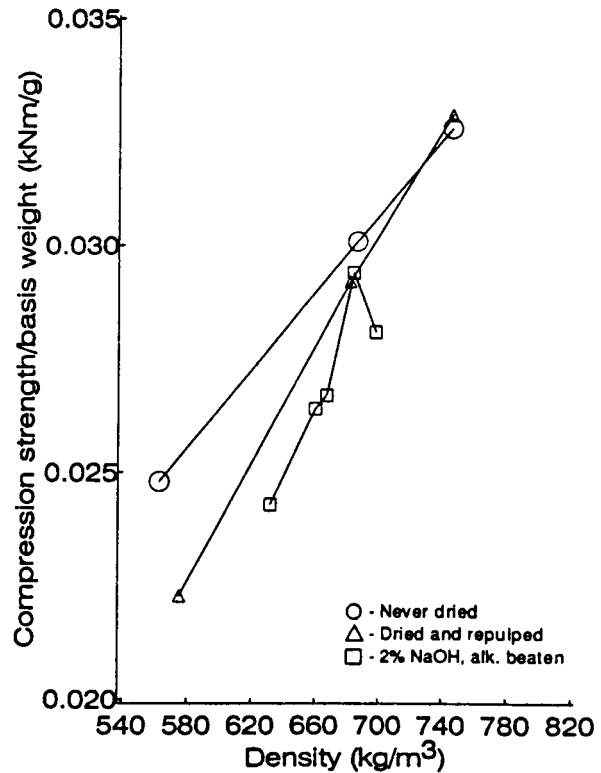


Figure 8. STFI compressive strength divided by basis weight for Hobart mixed, 2% NaOH treated, alkaline beaten, dried, repulped linerboard fiber as function of handsheet density.

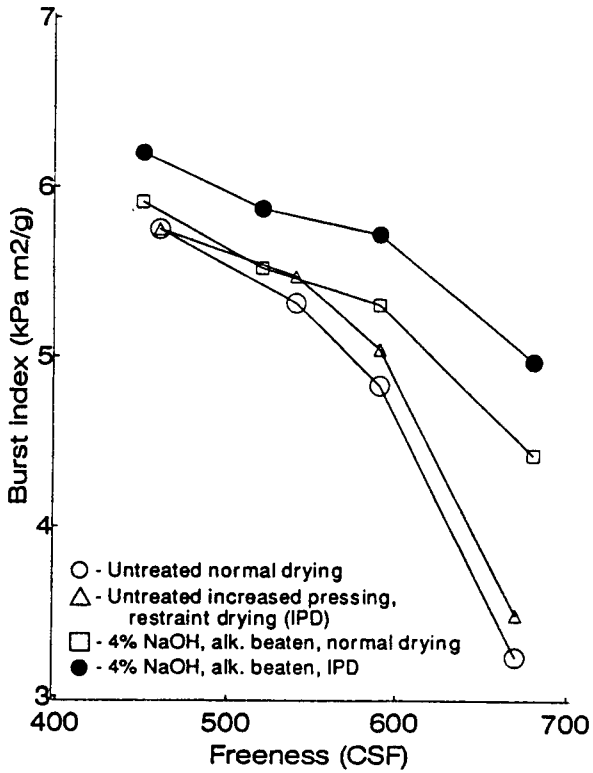


Figure 9. Burst strength for untreated and treated pulps as function of freeness.

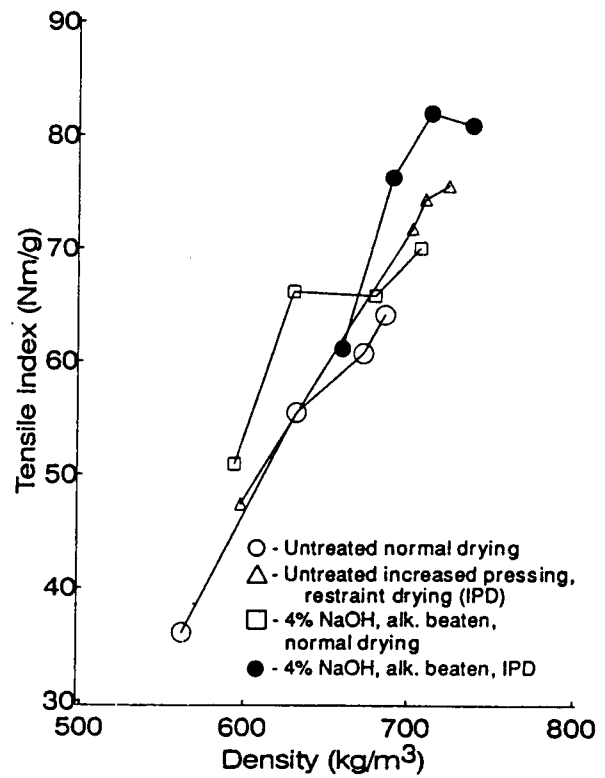


Figure 11. Tensile strength of untreated and treated pulps as function of handsheet density.

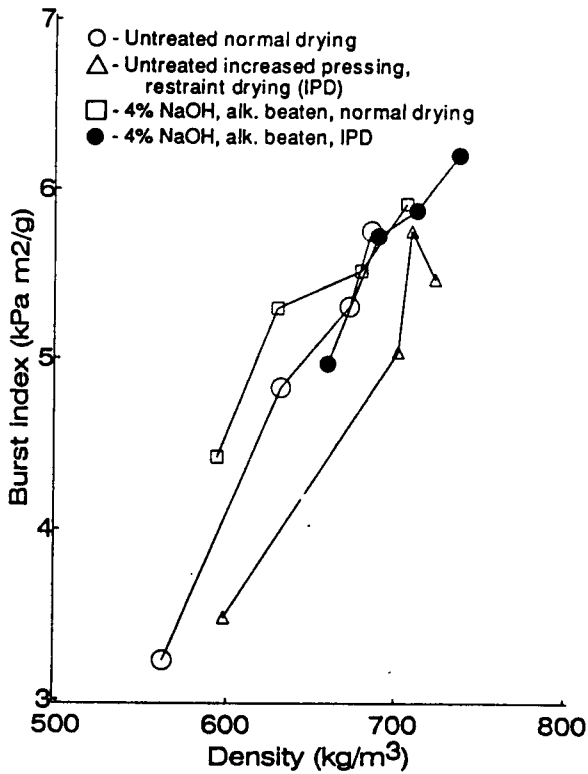


Figure 10. Burst strength for untreated and treated pulps as function of handsheet density.

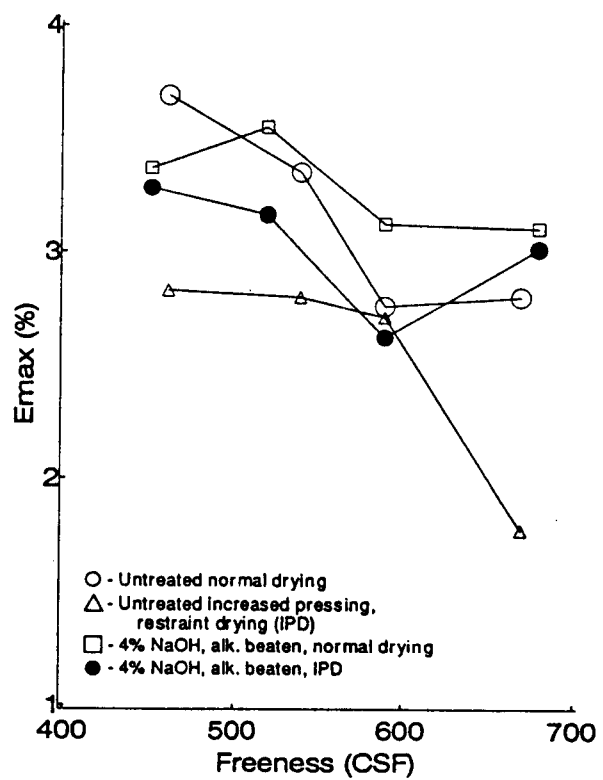


Figure 12. Elongation at failure for untreated and treated pulps as function of freeness.

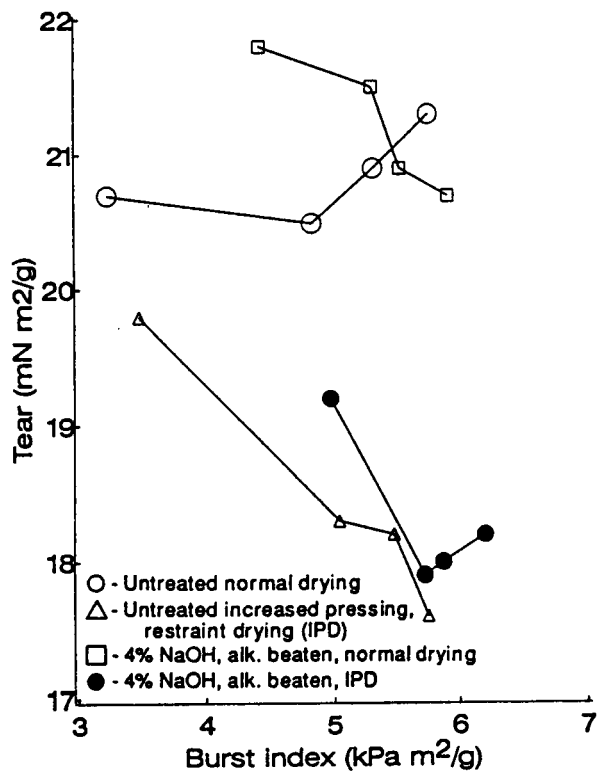


Figure 13. Tear strength of untreated and treated pulps as function of burst strength.

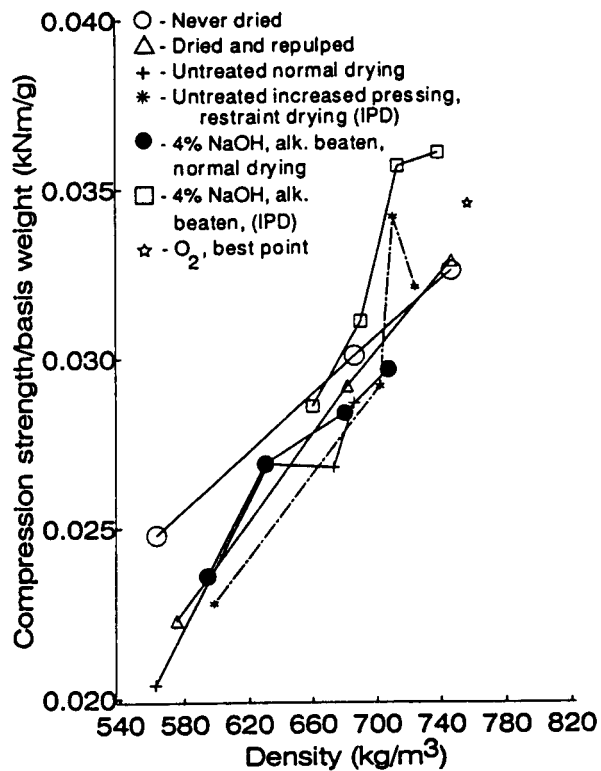


Figure 14. STFI compressive strength divided by basis weight for the untreated and treated pulps as function of handsheet density.

